**Attachment 3.3 – Supporting Documents**

**Workplan**

**Project C - Cottonwood Creek, Berenda Creek, and Dry Creek Arundo Eradication and Sand Removal**

**Madera Region – IRWM Implementation Grant Application**

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# Attachment 3.3 – Global Invasive Species Database:  Ecology of Arundo

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**Taxonomic name:** *Arundo donax* (L.)
**Synonyms:** *Aira bengalensis* (Retz.) J.F. Gmel., *Amphidonax bengalensis* (Retz.) Nees ex Steud., *Amphidonax bengalensis* Roxb. ex Nees., *Amphidonax bifaria* (Retz.) Nees ex Steud., *Arundo aegyptiaca* hort. ex Vilm., *Arundo bambusifolia* Hook. f., *Arundo bengalensis* Retz., *Arundo bifaria* Retz., *Arundo coleotricha* (Hack.) Honda., *Arundo donax* var. *angustifolia* Döll., *Arundo donax* var. *coleotricha* Hack., *Arundo donax* var. *lanceolata* Döll., *Arundo donax* var. *procerior* Kunth., *Arundo donax* var. *versicolor* (P. Mill.) Stokes, *Arundo glauca* Bubani., *Arundo latifolia* Salisb., *Arundo longifolia* Salisb. ex Hook. f., *Arundo sativa* Lam., *Arundo scriptoria* L., *Arundo versicolor* P. Mill., *Cynodon donax* (L.) Raspail., *Donax arundinaceus* P. Beauv., *Donax bengalensis* (Retz.) P. Beauv., *Donax bifarius* (Retz.) Trin. ex Spreng., *Donax donax* (L.) Asch. and Graebn.
**Common names:** arundo grass (English), bamboo reed (English), caña (Spanish), caña común (Spanish), caña de Castilla (Spanish), caña de la reina (Spanish), caña de techar (Spanish), cana-do-reino (Portuguese-Brazil), cana-do-brejo (Portuguese-Brazil), cane (English), canne de Provence (French), canno-do-reino (Portuguese-Brazil), capim-plumoso (Portuguese-Brazil), carrizo (Spanish), carrizo grande (Spanish), cow cane, donax cane (English), fiso palagi (Samoan), giant cane (English), giant reed (English), grand roseau (French), kaho (Tongan-Tonga Islands), kaho folalahi (Tongan-Tonga Islands), la canne de Provence (French- New Caledonia), narkhat (Hindi), ngasau ni vavalangi (Fijian-Fiji Islands), Pfahlrohr (German), reedgrass (English), river cane (English), Spaanse-riet, Spanisches Rohr (German), Spanish cane (English), Spanish reed (English), wild cane (English)
**Organism type:** grass
Giant reed (Arundo donax) invades riparian areas, altering the hydrology, nutrient cycling and fire regime and displacing native species. Long 'lag times' between introduction and development of negative impacts are documented in some invasive species; the development of giant reed as a serious problem in California may have taken more than 400 years. The opportunity to control this weed before it becomes a problem should be taken as once established it becomes difficult to control.

**Description**

*Arundo donax* is a very tall and robust bamboo-like, perennial grass with large, spreading clumps of thick culms to 6.1 m tall. The numerous leaves are about 5 cm wide and 30.5-61 cm long, and arranged conspicuously in two opposing ranks on the culms. The leaves look like those of a corn plant. Their margins are sharp to the touch and can cut careless hands. The inflorescence, appearing in late summer, is a 0.3-0.6 m long purplish, aging to silver, plume that stands above the foliage. Giant reed spreads from thick, knobby rhizomes. Once established, it tends to form large, continuous, clonal root masses, sometimes covering several acres. These root masses can be more than 1 m thick. The foliage dries to light brown in the winter and rattles in the wind. Striped giant reed (*A. donax* var. *versicolor*, has leaves with bold white stripes, and is a smaller plant, to 2.4 m tall (Christman, 2003; McWilliams, 2004).

**Occurs in:**

agricultural areas, coastland, desert, natural forests, planted forests, range/grasslands, riparian zones, ruderal/disturbed, scrub/shrublands, urban areas

**Habitat description**

*Arundo donax* is a hydrophyte, and grows best where water tables are near or at the soil surface. It establishes in moist places such as ditches, streams, and riverbanks, growing best in well drained soils where abundant moisture and sunlight is available. *A. donax* has also been demonstrated to prefer areas with enriched nitrogen levels. It tolerates a wide variety of conditions, including high salinity, and can flourish in many soil types from heavy clays to loose sands. It is well adapted to the high disturbance dynamics of riparian systems. *A. donax* inhabits USDA zones 6-11 (Benton *et al*, 2006; Ambrose & Rundel, 2007).

**General impacts**

Dense populations of *Arundo donax* affect riversides and stream channels, compete with and displace native plants, interfere with flood control, and is extremely flammable increasing the likelihood and intensity of fires. It may establish a invasive plant-fire regime as it both causes fires and recovers from them 3-4 times faster than native plants. It is also known to displace and reduce habitats for native species including the Federally endangered Least Bell's Vireo (*Vireo bellii*).

Its long, fibrous, interconnecting root mats of giant reed form a framework for debris behind bridges, culverts, and other structures that can effect their function and disturb ecosystems. Its rapid growth rate, estimated 2-5 times faster than native competitors, and vegetative reproduction, it is able to quickly invade new areas and form pure stands. Once established, *A. donax* has the ability to outcompete and completely suppress native vegetation, reduce habitat for wildlife, and inflict drastic ecological change (Benton *et al*, 2006; McWilliams, 2004; Ambrose and Rundel, 2007; Rieger & Keager, 1989).

**Uses**

*Arundo donax* is grown as an ornamental for the its striking appearance, purplish stems, and for the huge feather-like panicles of purplish flowers. It is the largest and tallest ornamental grass other than bamboo, and the tallest grass that can be grown outside the tropics. The large, thick and fluffy flower plumes are used in floral arrangements. *A. donax* is also used to make reeds for woodwind instruments and were once used for organ pipes. Giant reed is commonly planted in wet soils to reduce erosion (Christman, 2003).

In folk medecine, the rhizome or rootstock of *Arundo donax* is used for dropsy. Boiled in wine with honey, the root or rhizome has been used for cancer. This or other species of *Arundo* is also reported to be used for condylomata and indurations of the breast. The root infusion is regarded as antigalactagogue, depurative, diaphoretic, diuretic, emollient, hypertensive, hypotensive, and sudorific (Duke, 1997).

**Geographical range**

Native range: Afghanistan, Algeria, Azerbaijan, China, Cyprus, Egypt, Georgia, India, Indochina, Iran, Iraq, Israel, Japan, Jordan, Lebanon, Libya, Myanmar, Nepal, Pakistan, Saudi Arabia, Syria, Taiwan, Tunisia, Turkey, Turkmenistan, Ukraine, Uzbekistan

Known introduced range: Argentina, Australia, Bangladesh, Bermuda, Bolivia, Brazil, Cayman Islands, Chile, Cook Islands, Costa Rica, Dominican Republic, Ecuador, El Salvador, Fiji, French Polynesia (Polynésie Française), Gibraltar, Guam, Guatemala, Haiti, Indonesia, Italy, Kiribati, Mexico, Micronesia, Namibia, Nauru, New Caledonia (Nouvelle Calédonie), New Zealand, Nicaragua, Norfolk Island, Palau, Peru, Portugal, Samoa, South Africa, Suriname, Swaziland, Tonga, United States (USA), Uruguay, Venezuela

**Introduction pathways to new locations**

*Agriculture:*

*Floating vegetation/debris:*

*Landscape/fauna "improvement":*

*Nursery trade:* Canes traditionally cultivated for variety of uses - fencing, thatch, framing, musical instruments and woodwind reeds; carried esp. by Spanish colonists.

**Local dispersal methods**
*Garden escape/garden waste:* Available in nursery trade.
*Translocation of machinery/equipment (local):*
*Water currents:* Floods break up clumps of *Arundo donax* and spread pieces downstream where they can take root and establish new clones (McWilliams, 2004).
*Wind dispersed:* The hairy, light-weight disseminules (individual florets with the enclosed grain) are dispersed by wind (McWilliams, 2004).
**Management information**
Preventative measures: A Risk assessment of *Arundo donax* for Australia was prepared by Pacific Island Ecosystems at Risk (PIER) using the Australian risk assessment system (Pheloung, 1995), resulting in a score of 12 with a recommendation "to reject the plant for import (Australia) or species likely to be of high risk (Pacific)".

Chemical: The use of systemic herbicides such as glyphosate or fluazipop applied after flowering either as a cut stump treatment or foliar spray have been found to control *Arundo donax*. Caution should be taken when using such herbicides around water or in wetlands (Benton *et al*, 2005; PIER, 2008).

Physical: Hand pulling may be effective at removing small infestations of *Arundo donax*, but care must be taken to remove all rhizomes to prevent re-establishment. Cutting is not recomended unless the rhizomes are dug up, as tiny rhizomes can grow into new colonies. Burning is not recomended either as it has been demonstrated to aid the growth of *Arundo donax* because it regrows 3-4 times faster than native plants (PIER, 2008; Ambrose & Rundel, 2007).

Biological control: Native flora and fauna typically do not offer any significant control potential of *Arundo donax*. It is uncertain what natural controlling mechanisms for giant reed are in its countries of origin, although corn borers, spider mites, and aphids have been reported in the Mediterranean. A sugar cane moth-borer in Barbados is reported to attack giant reed, but it is also a major pest of sugar cane and is already found in the United States in Texas, Louisiana, Mississippi, and Florida. A leafhopper in Pakistan utilizes *A. donax* as an alternate host but attacks corn and wheat. In the United States a number of diseases have been reported on giant reed, including root rot, lesions, crown rust, and stem speckle, but none seem to have seriously impacted advance of this weed. Giant reed is not very palatable to cattle, but during the drier seasons they will graze the young shoots, followed by the upper parts of the older plants. However, in many areas of California the use of Angora and Spanish goats is showing promise for controlling *A. donax*. Also an unidentified stem-boring sawfly that appears similar to *Tetramesa romana* has been demonstrated to cuase significant damage to *A. donax*, and it is being tested in quarantine as a candidate biocontrol agent for it (McWilliams, 2004; Dudley *et al*, 2006).

Integrated management: A popular approach to treating giant *Arundo donax* has been to cut the stalks and remove the biomass, wait 3 to 6 weeks for the plants to grow about 1 m tall, then apply a foliar spray of herbicide solution. The chief advantage to this approach is less herbicide is needed to treat fresh growth compared with tall, established plants, and coverage is often better because of the shorter and uniform-height plants. However, cutting the stems may result in plants returning to growth-phase, drawing nutrients from the root mass. As a result there is less translocation of herbicide to the roots and less root-kill. Additionally, cut-stem treatment requires more time and personnel than foliar spraying and requires careful timing. Cut stems must be treated with concentrated herbicide within 1 to 2 minutes of cutting to ensure tissue uptake. This treatment is most effective after flowering. The advantage of this treatment is that it requires less herbicide and the herbicide can be applied more precisely. It is rarely less expensive than foliar spraying except on very small, isolated patches or individual plants (McWilliams, 2004).

**Nutrition**

*Arundo donax* photosynthesizes through C3 fixation which requires abundant sunlight and moisture. It has also been demonstrated to prefer areas with enriched nitrogen levels (Lewandowski *et al*, 2003; Benton *et al*, 2006; Ambrose & Rundel, 2007).

**Reproduction**

Reproduction of *Arundo donax* is primarily vegetative by way of rhizomes which root and sprout readily and layering in which stems touching the ground sprout roots. Layering has been demonstrated to expand *A. donax* as much as 7.4 times faster than spread by rhizomes but is thought to only occur within flood zones. *A. donax* tends to form large, continuous, clonal root masses, sometimes covering several acres. It very rarely produces seeds and very little is known about its sexual reproduction (Benton *et al*, 2006; Boland, 2006; McWilliams, 2004)

**This species has been nominated as among 100 of the "World's Worst" invaders**

**Reviewed by:** Tom Dudley Marine Science Institute University of California Santa Barbara & Natural Resource & Environmental Sciences University of Nevada, Reno. United States

**Principal sources:** McWilliams, John D. 2004. *Arundo donax*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Pacific Island Ecosystems at Risk (PIER)., 2006. Risk Assessment *Arundo donax* L., Poaceae

**Compiled by:** Profile revision: National Biological Information Infrastructure (NBII) & IUCN/SSC Invasive Species Specialist Group (ISSG)

To contribute information, please contact Shyama Pagad.

**Last Modified:** Thursday, 23 March 2006

# Attachment 3.3 – Photos of Arundo in Cottonwood, Berenda, and Dry Creek

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# Attachment 3.3 - Preliminary Comparison of Transpirational Water Use by *Arundo donax* and Replacement Riparian Vegetation Types in California

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***Preliminary Comparison of Transpirational Water Use by Arundo donax and Replacement Riparian Vegetation Types in California***

Report to Madera Co. RCD, Elissa Brown
From: Tom Dudley, Marine Science Institute, U.C. Santa Barbara
& Shelly Cole, Environmental Sciences Program, U.C. Berkeley

## Introduction

*Arundo donax* or giant reed is hypothesized to cause excessive losses of groundwater to the atmosphere, based on an assumption that it has high transpiration rate during photosynthesis relative to other riparian plant types, and that its large leaf surface area facilitates even greater water consumption and transport (Dudley 2000). Some initial comparisons do suggest that it may transpire almost double the amount of water as does a native willow in northern California under some circumstances (Zimmerman 1999, Hendricks et al. 2006). Researchers in Texas indicate that *Arundo* has high transpiration output but associated plant types were not compared in that case (Watt et al. 2008). In semi-arid riparian areas of California and the Southwest excessive transpiration by invasive plants potentially exerts pressure on natural or managed ecosystems by exhausting surface water and depleting groundwater (Shafroth et al. 2005). Documentation of such effects would provide a solid basis for implementing control programs for invasive plants such as *Arundo* if it can be shown that replacement by native or other plants that transpire less water could enhance water availability for wildlife and human uses.

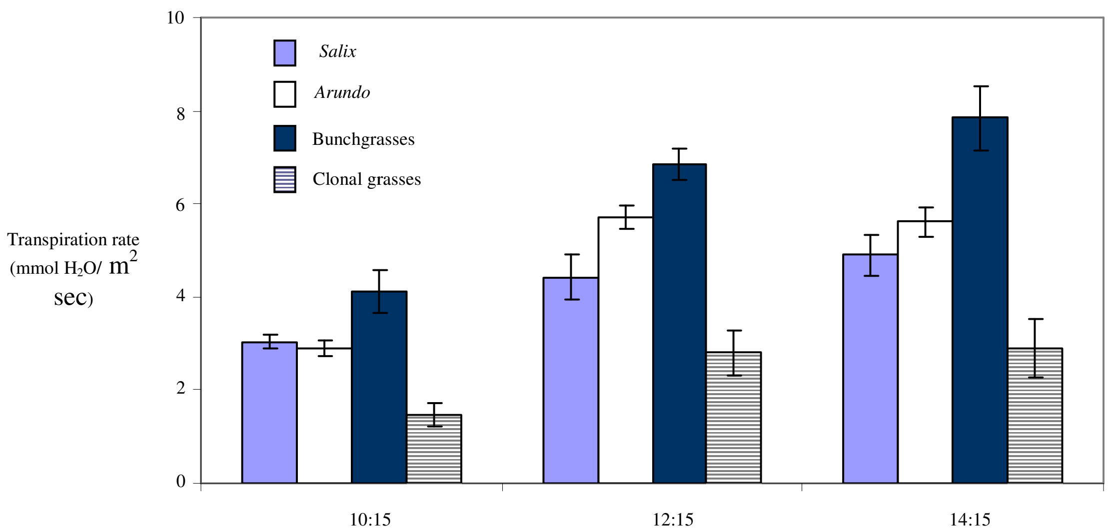
We conducted a comparison of water use by four vegetation types, including *Arundo*, a native willow, large-statured bunch grasses and prostrate, clonal grasses, to determine the relative amount of sub-surface water that are transpired to the atmosphere during the warm season in California. This trial study was conducted at the Hedrick Conservation Area (HCA), a private nature reserve on the Santa Clara River in Ventura County. *Arundo* and red willow (*Salix laevigata*) were plants that we had grown in an experimental ‘plantation’ for other ecological studies (Coffman 2006); the other plants were either installed in restoration efforts or existed naturally at the HCA within 200 meters of the plantation, and included ‘bunch grasses’ (*Leymus triticoides* – creeping wildrye*, Elymus condensatus* – giant wildrye) and ‘clonal grasses’ (*Distichlis spicata, Cynodon dactylon*). Weather data used for calculating moisture dynamics were from the nearby U.C. Coop. Extension Hansen Agricultural Center.

The trials were conducted at the beginning of September and consisted to 4 days for collecting data. Leaf-level moisture flux (transpiration) was measured using Lincoln Corporation portable photosynthesis unit (LiCor 6100) at three times of the day, mid-morning, mid-day and early afternoon, to reflect daily variation in temperature and light intensity. The LiCor test chamber would be used to measure moisture flux from two leaves on each test plant, the leaves chosen to be the uppermost (newest) on a given stem that had fully opened; measurements were replicated on a minimum of five plants for each treatment group (*Arundo*, *Salix*, bunchgrass, clonal grass). Whole plant transpiration was then estimated by extrapolating unit-leaf area moisture flux measurements to whole plant leaf area, which was determined by harvesting sub-portions of the test plants and measuring leaf dimension to calculate whole-plant leaf area.

## Results

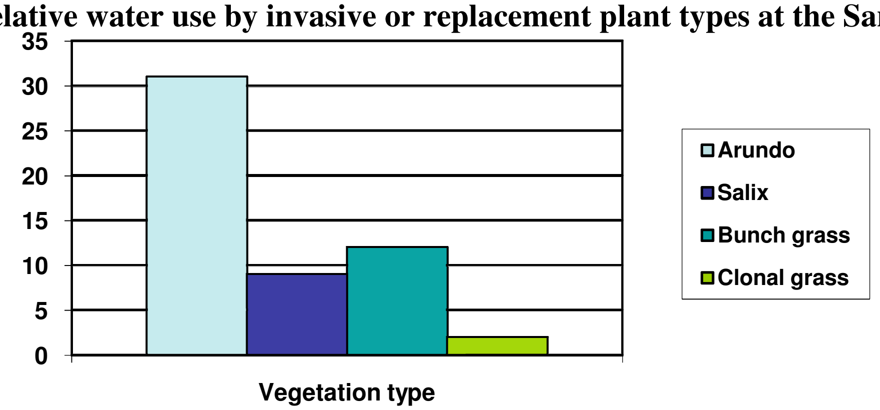
The following table presents values for transpiration (or water loss) through foliage of the experimental plants. These are estimates for a standardized leaf surface area, and indicate that generally willow (*Salix laevigata*) is roughly similar to *Arundo donax* on a leaf-area basis, that our 'bunch grasses' (*Leymus triticoides, Elymus condensatus*) are more water-consumptive, and 'clonal grasses' (*Distichlis spicata, Cynodon dactylon*) use substantially less water when standardized for leaf area. Note, however, that during the high light-intensity mid-day period, *Arundo* transpired approximately 25% more water than did the willow; these differences were statistically significant. This suggests that *Arundo* has an inherent higher capacity to continue transpiration (or photosynthesis) at a high rate when under excessive light conditions, while willows may respond to by reducing photosynthetic rate. Such photo-inhibition is well-documented in many plants, and it is likely that this dichotomy also exists between *Arundo* and willows too. This would translate into substantially larger daily ET rates for *Arundo*, once transpiration values are integrated over the full daylength period.

**Transpiration rates for target vegetation types at the Santa Clara River**




The more critical comparison, however, is transpiration on a per-unit ground area basis. We calculated the photosynthetic area, or leaf area, for 4 plants of each plant type, as well as the average ground area occupied by that plant (its 'footprint'). The estimated leaf area per $m^2$ for the four vegetation types at our study site on the Santa Clara River were: willow 1.1 – 2.9 $m^2$ ; *Arundo* 3.7 – 6.7 $m^2$ ; Clonal grasses 0.3 – 0.8 $m^2$; Bunch grasses 1.0 – 2.4 $m^2$. By using

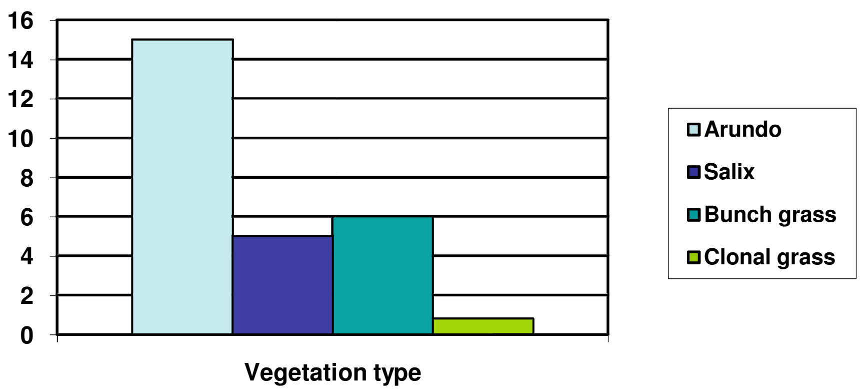
**Relative water use by invasive or replacement plant types at the Santa Clara River**



the mid-range values for leaf-area, and the mid-day transpiration rates, the relative water use by these 4 vegetation types is: *Salix* – 9 units water (on a relative basis); *Arundo* – 31 units; Bunch grasses – 12 unit; Clonal grasses – 2 units water.

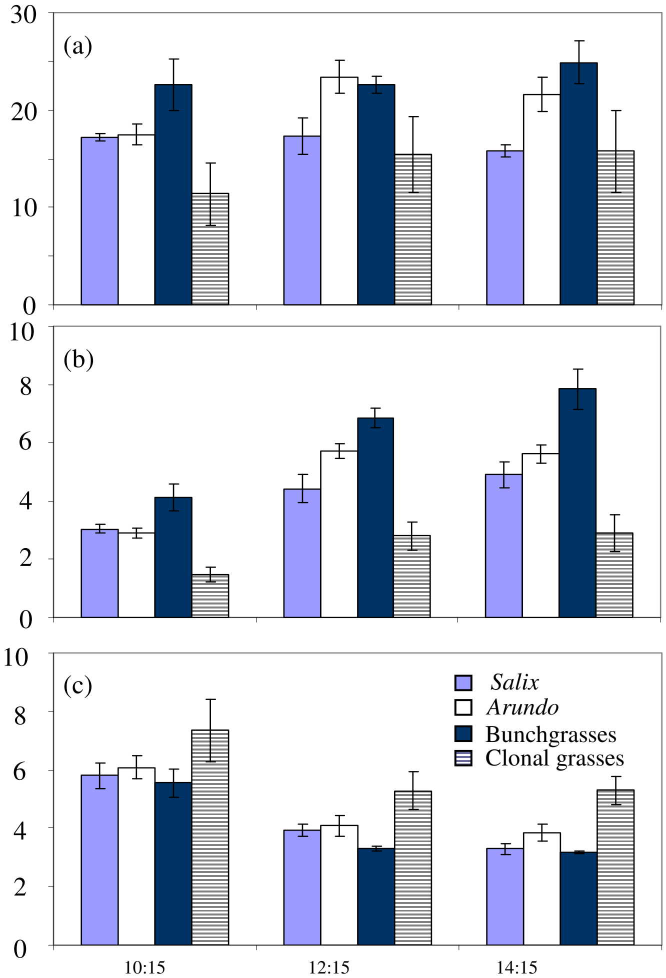
A rough prediction of the actual amount of water transpired to the atmosphere by each vegetation type can subsequently be calculated as the product of the transpiration volume per second over the time period that plants are photosynthetically active, and extrapolating this value to plant leaf area. For the late summer period when measurements were taken, we estimated the period of active photosynthesis as being 10 hours long (discounting morning and evening hours when light incidence is relatively low), and extrapolated interim hourly values between the three measurement points as a curvilinear relationship. This yielded a range of daily water use values from 0.015 $m^3$ (15 l.) per $m^2$ ground area with *Arundo* to 0.0008 $m^3$ (0.8 l.) for *Cynodon* and *Distichlis* clonal grass forms. That would be equivalent to 150 $m^3$ of water loss per hectare of *Arundo*-infested riparian area per warm, sunny day, or approximately 0.12 acre-feet per day.

**Estimate daily mid-summer water use by target plant types (liters per day per $m^2$)**




These values could be further extrapolated to annual water use quantities by estimating the transpiration rates per unit time at different times of the year, but for several reasons this is beyond the scope of the preliminary data we have generated. For purposes of discussion, we might assume that these mid-summer transpiration values are representative of 4 warm months, that 4 spring and fall months produce half as much water use, and during winter there are 4 months of transpiration rates about 15% of summer rates. Based on these conjectures, *Arundo* may remove approx. 3.0 $m^3$ of groundwater to the atmosphere for every $m^2$ of infested land area, compared with 1.0 to 1.2 $m^3$ for native vegetation; 0.16 for groundcover 'clonal' grasses; this would be equivalent to drawing down the groundwater level by the same numerical relationship (e.g. 3 m by *Arundo*) if the whole system was comprised of that vegetation type. We cannot stand by these estimates, however, because transpiration is highly dependent upon air temperature and relative humidity, on water availability, and on the amount of total leaf area and shading that would exist at different times of the year. Although *Arundo* is presumed to be more metabolically active during winter months than are willows and so would certainly be relatively even more water-consumptive at that time of year, we are unable to make a rational evaluation of actual seasonal water use because of the lack of appropriate data needed to make such calculations.

The following graphs of PS rates and Water Use Efficiency expand the relationships described previously (the above Transpiration graph is 'b'), although they are more complex than is easily explained in this preliminary report. WUE suggests that the clonal grasses are most efficient at photosynthesis with respect to water used, while *Arundo* is marginally more efficient than the willows it has displaced.




The (a) photosynthetic rate (µmol/m$^2$ sec), (b) transpiration rate (mmol/m$^2$ sec) and (c) water use efficiency (mmol $CO_2$/mol$H_2O$) of study plants at three time periods. *n*=5 and bars indicate ±1 SE.

**Discussion/Preliminary Conclusions**

It appears that under warm-season conditions in semi-arid regions *Arundo* uses roughly three times as much water as do moderate sized replacement species (red willow, ryegrasses) that also provide some habitat value for wildlife, and about 15 times more water than does a low-quality grass such as native saltgrass or introduced bermudagrass. This may translate to roughly 0.12 acre-feet of water use by an acre of *Arundo*-infested landscape, one-third that among by willows (0.04 ac-ft) and large grasses (0.05 ac-ft), and somewhat less that 0.01 acre-feet by low-growing native or exotic grasses.

One caveat is that there are certainly areas where *Salix* and other plants have a greater (or less) leaf surface area than we found at this site, so our results are not robust across a larger region without correction for the leaf area present per meter-square of land surface. We did, however, find roughly similar results when the same approach was taken in comparing *Arundo* and *Salix exigua* in northern California (Zimmerman 1999). In that study, transpiration per unit leaf area was more equivalent between the two taxa, but the leaf area of *Arundo* was approximately double that of *Salix* so the water losses through *Arundo* were consequently about double that lost through willow photosynthesis.

It is important to note that these are very preliminary results, and firmer conclusions must wait until we do a longer series of PS/transpiration trials under a full range of environmental conditions, and at different times of the year. The degree of soil saturation greatly influences transpiration, and the plants in this study had ample water supplies available while under other circumstances plants may experience variable degrees of water-stress (and stress may differ among species) when results would be much lower. Also, these measurements were taken under full sunlight, but portions of plants obviously are shaded to different degrees, which will reduce photosynthesis, and thus, transpiration. The shade produced by *Arundo* may, in fact, be greater than that created by the other species which would further influence transpiration estimates. Plant density can further influence the local microenvironment, particularly by creating locally high humidity conditions which would also lead to over-estimates of water use by testing leaf surface transpiration in the open away from the plant under canopy, although the equipment can partially compensate for such humidity effects.

Also, we need to develop more accurate leaf area assessments, which will require much more extensive harvesting and measuring of plant parts. The stomatal surface area should be accurately described as well, because some plants have greater stomatal density on the same leaf surface area (even on one side vs. both sides of the leaf), which should be understood in accurately assessing water use. Some stems have photosynthetic tissue, which should be included in transpiration estimates.

In future studies we will determine how PS differs based on leaf types (new vs. old, sun vs. shade leaves) and at different positions in the plant. In particular, we intend to measure how shading affects leaf metabolic activity, but some very preliminary tests indicated that *Arundo* has higher PS activity in the shade than does *Salix*, which would certainly tend to increase the relative difference in water use by the two. That, in combination with estimates under low water availability levels, I think will certainly show that *Arundo* is very significantly and substantively worse than any of the other plant types, in terms of water loss from regional rivers and groundwater.

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Zimmerman, P. (1999) Rates of transpiration by a native willow, *Salix exigua*, and by a non-native invasive, *Arundo donax*, in a riparian corridor of northern California. IN:Proceedings of the California Exotic Pest Plant Council. California Exotic Pest Plant Council, Sacramento, California

# Attachment 3.3 – Valley Floor Groundwater Level Decline

**Madera IRWMP Figure 5-5**

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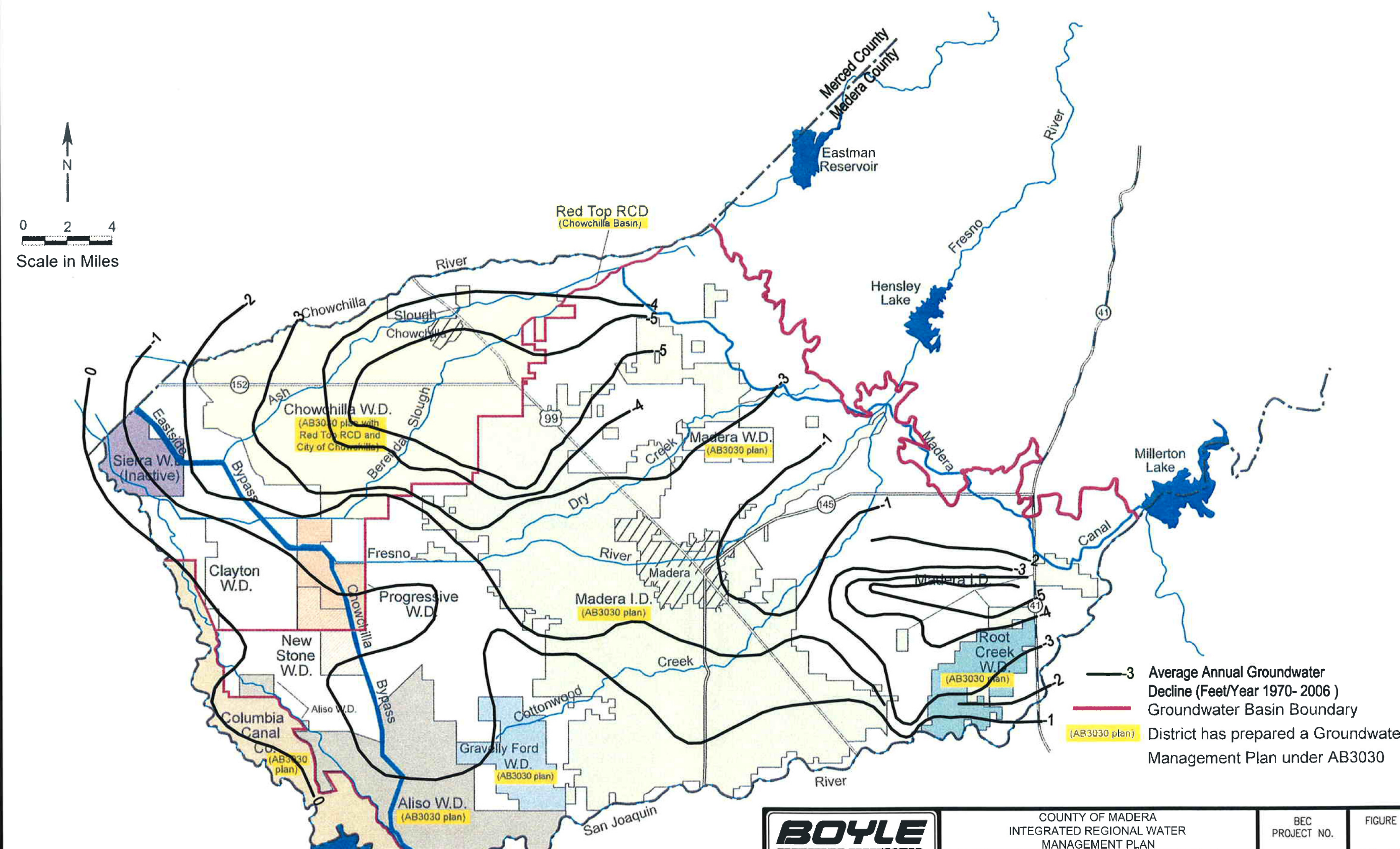


SOURCE:
BASE MAP - TODD ENGINEERS, 2002
WATER LEVEL DATA - KENNETH D. SCHMIDT & ASSOCIATES, 2007

BOYLE ENGINEERING CORPORATION
1360 E. Spruce Avenue Suite 101
Fresno, California 93720 559-448-8222
WWW.BOYLEENGINEERING.COM

COUNTY OF MADERA
INTEGRATED REGIONAL WATER MANAGEMENT PLAN

VALLEY FLOOR GROUNDWATER LEVEL DECLINE

BEC PROJECT NO. 22203.00

FIGURE 5-5

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